Analyzing the Potential of Compressed Earth Blocks as a Feasible and Sustainable Building Material

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Abstract: The most popular building material in India is burnt clay brick, which not only contributes significantly to greenhouse gas emissions but also removes a large amount of topsoil from agricultural land each year. Traditional burned brick places a great deal of strain on the environment because the burning process produces greenhouse gases. Compressed Earth Block (CEB) is among the eco-friendly building materials. It is also known as a pressed earth block or a compressed soil block. It is created by mixing the proper ratios of non-expansive clay, non-expansive subsoil, sand, and aggregate. Earth blocks are created by compressing wet earth and letting it dry in a controlled atmosphere. A machine that may be powered manually or electrically is used to compress the damp earth. The compressed earth blocks have the advantage of being constructed from local clays and soils that may be found on or close to the construction site, which contributes to their sustainability. For sustainable development, the Compressed Stabilized Earth Block (CSEB) provides the possibility for natural, energy-efficient, environmentally friendly, and agriculturally compatible building materials. This paper examines the case of Compressed Earth Blocks (CEBs) for load-bearing wall construction as well as filler material in buildings. It also discusses the engineering viability and properties of such compressed earth bricks. The paper concludes that compressed earth bricks are a realistic alternative to regular bricks with additional benefits.
***Keywords*:** building material, energy efficiency, insulation, insulated tiles, sustainable architecture

1. Introduction

The most common building material in use today is soil. In ancient times, mud block wall building with a different kind of stability was the norm. A building material constructed mostly from damp soil compacted at high pressure to form blocks is known as a compressed earth block (CEB), also known as a pressed earth block or a compressed soil block. Compressed earth blocks are made using a mechanical press and a suitable mixture of non-expansive clay, aggregate, and fairly dry inorganic subsoil. If the blocks are stabilized with a chemical binder such as Portland cement they are called compressed stabilized earth block (CSEB) or stabilized earth block (SEB). Typically, around 3,000 psi (21 MPa) is applied in compression, and the original soil volume is reduced by about half. Due to the development of cement and the rising manufacturing of burnt clay bricks over the previous century, this form of block was neglected. Now, there is a rise in interest in stabilized soil blocks due to the excessive energy used in their creation. Due to the buildup of mineral and plant residues, the top layer of soil, often known as "topsoil," typically contains a sizeable amount of organic matter. The subsoil, which is located beneath the topsoil and is appropriate for use as a building material, contains little to no organic matter. Rammed earth is used to create bigger forms, such as an entire wall or more at once, as opposed to CEBs, which employ smaller formwork into which earth is poured and manually tamped down. Mud bricks, as opposed to CEBs, are not compacted and solidify when they dry naturally through chemical reactions. A correctly constructed CEB often has higher compression strength than a standard mud brick. For compressed earth block, construction standards have been created (Minke, 2000).

CEBs are installed on walls utilizing conventional bricklaying and masonry methods. When building during freeze-thaw cycles causes stability concerns, cement mortar may also be used. The mortar can simply be basic slurry formed of the same soil/clay mix without aggregate, applied or brushed very thinly between the blocks for bonding. Chemical binders like Portland cement are added to the blocks to strengthen their stability. These blocks are known as compressed stabilized earth blocks, or CSEB. These blocks are additionally occasionally referred to as stabilized earth blocks (SEB). When paired with other green building methods and performance, the properties of the compressed earth block help to create the ideal ecologically friendly structure. When used to fill in a wood frame, an interior wall, or the region around a masonry heater, it will provide your home the inertia necessary for accurate temperature management. When it has enough external insulation, a compressed earth block wall satisfies all the criteria for efficient heat regulation (Prasad, 2020). In particular for residences, sustainability is the main advantage of CEB. Comfortable, cooler in the summer and warmer in the winter, CEBs are an improvement. When the temperature needs to be changed, they do it with less energy. They may easily adapt to beautiful, intricate designs. With some restrictions, you can do whatever you want with the walls because they are load bearing (Powell, 2021). Figure 1 shows some compressed earth blocks left for sun drying.

Figure 1. Compressed earth blocks

2. Basic Components of Compressed Earth Blocks

Very coarse sand, coarse, medium, and fine sand, silt, and clay are among the main components of soil that are present in varied ratios. Sorting the soil according to its particle size is the typical procedure for figuring out the ratios. According to conventional wisdom, soils are categorized based on their granulometric analysis and by the description of the main fundamental component, which is sandy, silty, or clayey (Schroeder & Dickinson, 1996). . To facilitate classification, however, the basic soil components have been grouped according to particle size, as follows:

Coarse particles, or sand, from 4.76 mm to 0.074 mm in size

Fine particles (silt and clay), less than 0.074 mm in size (ASTM No. 200 sieves)

2.1 Coarse Particles

Sand: This might be viewed as the inert and structural component of soil. When damp, it is stable; when dry, it is unstable. Internal friction in sand is very high. It is not cohesive or malleable. When dry, it doesn't shrink. When pressure is applied to its surface, it is permeable and compresses almost instantly.

2.2 Fine Particles

Silt: Although though silt particles are too small to be seen with the human eye, they nonetheless feel gritty when they are between the teeth. Silt has minimal internal friction or cohesiveness. When worked, the loudness might alter. Compacting is challenging.

Clay: This particular type of soil has significant chemical and physical characteristics. Clay is very malleable and easily adopts the appropriate shape. It is a smooth-to-the-touch substance that becomes sticky when wet. Dried clay significantly increases in volume when it absorbs water, but when it dries, it shrinks back to its previous size, which causes fissures to appear in the mass. When pressure is applied to its surface, it is almost impermeable and compresses very slowly. Soil stabilization is a technique used to enhance mud buildings. The term "soil stabilization" refers to a number of procedures that are used to improve the suitability of natural soils for use as building materials. The addition of stabilizing chemicals boosts the best aspects of soils while also giving the other traits that they do not have on their own. In terms of value addition to the benefits of using soil as a building material, the cost of soil stabilization is quite cheap.

3. Addition of a Binding Agent

This technique involves combining soil with an agent to ensure that its particles bind together and stay firmly joined and unaffected by changes in moisture content, creating a solid and extremely durable material. Portland cement is typically employed as a binding agent. It is a mixture of cement, water, and soil. The utilization of the proper ratios of soil, cement, and water is essential for producing construction material of a high caliber. The required percentage of cement required for different types of soil is listed in Table 1.

Table 1. The percentage of cement required for different types of soil

Type of soil	Normal percentage of cement
Sandy	4.75-9.10
Silty	8.35-12.5
Clayey	– 15.4 (not recommended for use)

Each type of soil requires a specific degree of moistness if it is to be compacted correctly. Broadly speaking, the total amount of water varies between 8 percent and 16 percent by volume.

4. Manufacturing Process of Compressed Earth Blocks

The manufacturing of stabilized soil blocks will be as per IS code 1725. Stabilized soil blocks have been used to build numerous structures, notably those in India. This is mostly due to stabilized soil blocks' low carbon footprint and energy efficiency. The soil blocks are an alternative to blocks made of concrete and burned clay bricks. Before the compressed earth brick can be made, proper approval is necessary since it might not be strong enough and might have problems with weathering and durability. We might not be able to use the earth block even though it has sufficient strength and falls short of expectations in terms of durability performance. A stiffened plate lid that can be locked down after closing is provided for the mould. Molds of two sizes are typically used and are interchangeable. The two moulds can create blocks with respective dimensions of 23 x 190 x 100mm and 300 x 145 x 100mm. The correct amount of earth must be measured out using the provided scoop before adding it to the mould (Adlakha, 2019). This technique can produce blocks using molders that are powered by motor or operated by hand. To compact soil cement into blocks of the necessary size for large manufacturing, hydraulic machines are utilized. The blocks from these machines are consistent in strength and dimension, as long as standard procedures are followed for quality control. The Advanced Earthen Construction Technologies machines are good examples of quality mechanically operated machines (Graham & Burt, 2001). Figure 2 shows the semi-mechanized portable machine and Figure 3 shows an automatic compressed earth blocks making machine.

Figure 2. A semi-mechanized portable machine

The block is created by compressing the soil-cement combination in the press chamber. When a force is applied, the soil-cement mixture is compressed, which lowers the fraction of voids and raises the material's density. The higher the density may be increased, the less porous the soil will become. The amount of moisture must fall within a specified range and not be too high (Prasad, 2020).

Figure 3. An automatic compressed earth blocks making machine

The process of manufacture of soil-cement blocks involves the following five steps (Adhlakha, 2019):

4.1 Analysis of the Soil

Sand, silt, and clay are the three constituents of soil. According to particle size, is the coarsest of the three components, and clay is the finest. A well-graded soil produces quality work. Blocks should generally be made from soil that is 33% fine, 33% silt, and 33% sand. Adding 5 to 10% cement by volume results in rather high-quality bricks and blocks.

4.2 Sifting of the Soil

Before soil can be effectively combined with cement and crushed into blocks, it must be dried and sieved (to eliminate large lumps, stones, leaves, and other contaminants). For sifting soil, strong frames with metallic meshes might be employed.

4.3 Preparation of the Mix

The mix from which the blocks will be pressed can be prepared once the earth has been dried and sifted. The quantity of Portland cement needed will vary depending on the soil's makeup. Sandier soils call for 5 to 9% volume cement. Cement is used as a stabilizer in silty soils (8–12%) and clayey soils (12–15%). It's not advised to use more than 15% by volume. Cement, soil, and any additional components—such as sand or clay—that may be required should all be well combined. Once all the materials have been well dry-mixed, water is gradually added until the damp soil cement gets the desired consistency. It is important to keep mixing until the mixture's color is uniform. It is advised that blocks be cast within 30 minutes of the mixture because if the soil-cement mixture is allowed to dry out much longer, the strength and durability of the blocks would decrease.

4.4 Compaction of the Earth Blocks

The machine's mould is filled with the prepared mix, and pressure is then applied. The block is removed from the mould and stacked after being compacted. Care must be taken when handling and stacking the blocks because they are fragile when they are first formed. Figure 4 shows a manual compressing apparatus to create compressed stabilized earth blocks.

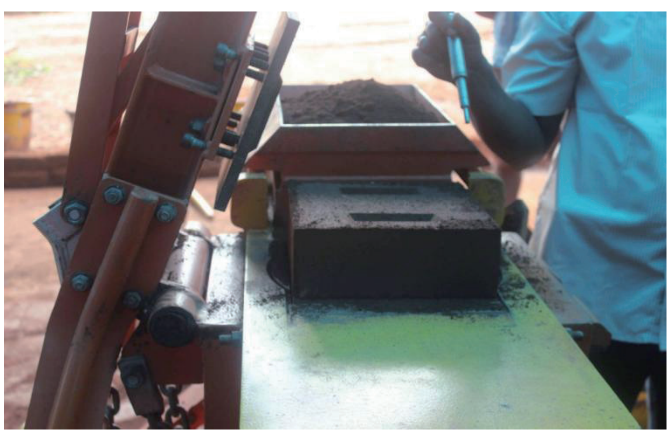

Figure 4. Compressing apparatus to create compressed stabilized earth blocks

4.5 Curing of the Blocks

As soon as you can, place the blocks in a shady area with protection from the sun and rain on a level, absorbent surface. Place each block on its edge and leave enough room between them so that they do not touch. The blocks must be allowed to dry gradually without experiencing any abrupt temperature changes. Therefore, the first twenty-four hours after they are made require strict moisture control to prevent them from drying out completely all at once, this could degrade the material's quality. Blocks must be thoroughly sprayed three times per day with the fine water spray for 15 days after 24 hours of de-molding. Blocks must be properly sprayed three times per day with the fine water spray for 15 days after 24 hours of de-molding. The strength of the block will increase as it dries more slowly (Figure 5).

Figure 5. Stacking curing and protection of earth stabilized blocks

5. Size of the Earth Blocks

The modular sizes of stabilized soil blocks are given in Table 2. The non-modular sizes are also feasible with appropriate molds.

Table 2. The modular sizes of stabilized soil blocks

Length (mm)	Width (mm)	Height (mm)
290	90	90
290	140	90
240	240	90
190	90	90
190	90	40

6. Walling with Soil Cement Blocks

6.1 Bonding of the Blocks

Bonding is the method used to arrange blocks in a wall. The careful arrangement of all the joints to ensure the proper transmission of vertical loads is a necessary condition for proper bonding. In other words, alternate courses are planned out in a way that prevents vertical seams or joints between one course and the one below from lining up (Figure 6).

Figure 6. Masonry wall using compressed stabilized earth blocks

6.2 Mortar Requirements

The combined strength of the mortar and the blocks determines how strong a wall will be. It is possible to produce blocks with strength of 30 to 60 kg/cm^2. In a wall subject to vertical pressures, blocks and mortar of similar strength will support the pressure in an equal manner; but, if there is any weakness in the mortar, the blocks will be susceptible to shearing stress, which invariably leads to cracks and fissures. Using low-strength blocks with high-quality mortars or high-strength blocks with weak mortars is a mistake since, in the latter case, the failure will be in the blocks rather than the mortar, in contrast to what happens in the former. In the construction of a soil-cement wall, water absorption by the blocks from the new mortar must be taken into consideration. It is advised to moisten the surface of the blocks in touch with the mortar to ensure there is enough water for the mortar to set properly (Figure 7).

Figure 7. Construction of masonry wall using compressed stabilized earth blocks

6.3 Fixing of Frames

Concrete-in-situ blocks are used to hold the Door / Window frame holdfasts, like in a brick masonry wall with burnt bricks.

7. Earthquake Resistance of the Blocks

In general, soil cement can endure some shocks or strains brought on by seismic events. Tensile stresses that cannot be absorbed by the soil-cement material may develop in areas that are prone to very strong seismic disturbances; it is therefore desirable to provide vertical reinforcement to absorb stresses of this nature. At wall connections, enough vertical reinforcement is offered in accordance with IS: 4326. In seismic areas, it's crucial to construct walls with a continuous beam or band that adds rigidity and supports the stability of the home. According to IS 4326, a lintel band is also laid. Figure 8 shows an institutional building made from compressed earth blocks in New Delhi, India.

Figure 8. An institutional building made from compressed earth blocks in New Delhi, India

8. Sustainability Characteristics and Energy Savings of CSEB

Energy consumed in manufacturing 1000 bricks and that in manufacturing cement used in an equivalent volume of cement stabilized soil blocks using 8% cement have been worked out. Energy used in manufacturing 1000 bricks is 6.90 x 105KCal while as that used in manufacturing approx. 320 Kgs of cement needed to stabilize the equivalent volume of soil blocks which is 2.71 x 105 Kcal. Thus there is a gross saving of 60.72% in energy consumed.

8.1 Low Embodied Energy

The total amount of energy used by all of the processes involved in creating a building is referred to as its embodied energy footprint. This energy covers the extraction and processing of natural resources, the production of building-essential materials, their transportation to the construction site, and the energy required to actually construct the building. While operational efficiency of the home is one of the main tenets of home sustainability, most sustainable builders and architects also consider the embodied energy footprint. This is important because operational efficiency gains may actually be offset by the higher embodied energy footprint that comes with new home construction. Because of this, many sustainability experts believe that remodeling an older house is frequently more environmentally friendly than developing a new house that uses less energy (Kamal, 2016). Compressed earth blocks can be constructed from local soils and clays that can be obtained on or close to the building site, which is the most significant sustainability benefit that comes with them in this context. The walls will effectively have a zero embodied energy footprint because these blocks are produced using a mechanical press that can be transported to the construction site. Compressed earth block walls can be constructed using locally with little training. Table 3 lists the sustainability and environmental friendliness of compressed stabilized earth blocks.

Table 3. Sustainability and environmental friendliness of CSEB

Initial Embodied Energy Per M^3	Carbon Emissions (Kg of Co2) Per M^3
CSEB = 572.6 MJ / m^3	CSEB = 51.5 Kg / m^3
Country Fired Brick (CFB) = 6,122.5 MJ / m^3	Country Fired Brick (CFB) = 642.9 Kg / m^3

8.2 Low to Zero Carbon Emission

Almost no carbon emissions can be produced by compressed earth blocks. According to engineers who have mastered this method, 65% of all soils are appropriate for compressing earth block walls, which eliminates the need to move soil to other locations. Compressed earth bricks can be formed in manual presses, in contrast to burnt bricks, which must be processed and manufactured using a lot of energy and emit a lot of carbon dioxide during the firing process. The sun and wind can naturally dry them. As a result, construction using burnt bricks requires several times as much energy as construction using compressed earth blocks. Table 4 shows the energy effectiveness of compressed stabilized earth blocks.

Table 4. Energy effectiveness of compressed stabilized earth blocks

Initial embodied energy (MJ/m^3 of materials)	Carbon emission (Kg of CO_2 /m^3 of materials)
CSEB are consuming 11 times less energy than country fired bricks	CSEB are polluting 13 times less than country fired bricks
CSEB produced on site with 5 % cement = 548.32 MJ/m^3 Country fired bricks = 6,122.54 MJ/m	CSEB produced on site with 5 % cement = 49.37 Kg of CO_2 /m^3 Country fired bricks = 642.87 Kg of CO_2 /m^3

8.3 Thermal Mass

Compressed earth blocks have the additional advantage of bringing a significant quantity of thermal mass into your home, which may then be used for passive solar heating to assist control the interior temperature of your home and lower your heating and cooling demands. Also, because these bricks contain a significant amount of clay and soil, they will naturally "breathe," regulating indoor humidity levels and enhancing the quality of the air inside. Houses constructed on compressed earth blocks will have an internal relative humidity range of 40% to 60% (Kamal, 2011).

8.4 Zero Wastage

Compressed earth block walls will naturally reintegrate back into the earth when a residence made of them needs to be torn down after a lifetime of use. This will significantly lessen the quantity of building waste that currently takes up a large portion of the country's landfills. Earthen blocks can be viewed as a cradle to grave product in this situation (Roberts, 2019).

9. Advantages of Compressed Earth Blocks

The Buildings constructed of compressed earth blocks exhibit numerous benefits (Prasad, 2020).

9.1 Feasible for Load Bearing Structures

It is possible to create load-bearing, structurally sound walls out of earth. Earthen walls can be strengthened with additional structural components to offer earthquake resistance. Buildings made of earth are strong and weatherproof. Earthen walls are water-resistant when coated with a water-resistant material. They withstand occupation and destruction by insects like termites and ants.

9.2 Sustainable Building Material

Earth Blocks have less than ten times the embedded energy and carbon emissions of burned bricks. When opposed to the intense heat required to create cement-based blocks and the firing process needed to create clay bricks, earth blocks require very little energy to manufacture. Earth Blocks reduce their environmental impact even after construction. Low maintenance and interior heating and cooling costs are two financial advantages. When compared to concrete block structures, earth block structures can use up to 20 to 30 percent less energy to heat and cool. Using current compressed earth block technology also results in lower construction costs. There are various ways to stabilize a substance, including chemical stabilization, granular stabilization, and compaction/densification (Kamal & Husain, 2015).

9.3 Thermal Performance

Because of its substantial thermal mass, the earth's structure maintains a constant internal temperature. In particular, it traps heat produced internally and balances daily changes. Earth Blocks walls add thermal mass, which can be utilized for passive solar heating to regulate inside temperature and reduce heating and cooling needs. These bricks will also naturally "breathe," controlling indoor humidity levels and improving the quality of the air because they contain a considerable quantity of clay and soil.

9.4 No Emission of Toxic Gases

Earth blocks are one of the few types of construction materials that don't emit toxic fumes. The blocks do not emit any hazardous chemicals like most conventional building materials because they are comprised of natural resources. Relative humidity levels enhance the quality of the indoor air in earthen constructions. Poor indoor air quality, which is much improved by this humidity control, is the root cause of many common ailments that are commonly attributed to the change in seasons.

9.5 Good Acoustical Properties

Buildings made of soil are quiet and have little sound transmission.

9.6 Fire Retardant

Earth has a 4-hour rating for fire resistance. Unlike other facade materials, a structure composed of compressed earth bricks is almost completely fireproof. This is one of the most important benefits of using earth blocks.

9.7 Limits Deforestation

No firewood is required to make CSEB. It will protect the woods, which are rapidly disappearing globally as a result of resource mismanagement and hasty development.

9.8 Reduces Imports

By using locally available, semi-skilled labour, there is no need to import expensive materials from far away or move heavy, expensive building materials across great distances.

9.9 Promotes Local Jobs

40 to 45 percent of the overall cost is attributed to labour in the production of compressed stabilized earth blocks (CSEB). This supports endogenous development and local employment. CSEB enables low-skilled and jobless individuals to acquire a skill.

10. Disadvantages of Compressed Earth Blocks

A few restrictions apply to the use of compressed stabilized earth blocks in building construction. Incorrect soil identification will result in soil not being available. The fundamentals of production and utilization are not understood. Because of the opposite examples, there is poor societal acceptance. A substantial amount of time must be spent on production. After the block has been cast, it takes roughly three weeks for the block to cure. The compressed earth blocks could readily dissolve if exposed to rain. Hence, depending on the type of construction, specific consideration must be given. In comparison to cement blocks, it is weak. The strength is enhanced by the addition of stabilizers such Portland cement. A lack of stability may result in products of poor quality. Compared to concrete, it performs technically poorly. Long, lofty buildings with wide spans are challenging to construct. Due to a lack of studies, there may be a failure in stabilized brick walls. Also, problems with the materials and mixture may prevent the expected strength from developing.

11. Potential of Compressed Earth Blocks in the Building Construction Industry

The type of building materials used in the construction industry has significant effects on local development requirements for providing appropriate low-cost housing for the constantly growing populations of developing countries. Research from the past has shown that compressed earth bricks have many advantages over traditional burnt bricks. In the end, compressed stabilized earth bricks are more environmentally friendly, stronger, more durable, and have similar thermal conductivity. Also, it has been demonstrated that compressed earth bricks exhibit durability on par with regular burnt clay bricks. Thermal value testing revealed that the thermal conductivity of CEB met the design thermal specifications for clay masonry and building codes. The full-scale production of compressed stabilized earth bricks has shown that this type of building material has a great potential in the future for low to medium cost housing construction and contributes to sustainable development, even though economic potential may attract more people than ecological reasons. Its versatility without sacrificing cost effectiveness allows it to be used in hot climates as well. There are numerous methods that may be used to build affordable housing with CEB that have each been proven to be successful in their own way. The block needed for a specific function can be obtained by utilizing various stabilizing agents and compositions. Figure 9 and Figure 10 shows the application of compressed earth blocks in residences and low rise building construction.

Figure 9. A residence made from compressed earth blocks, India.

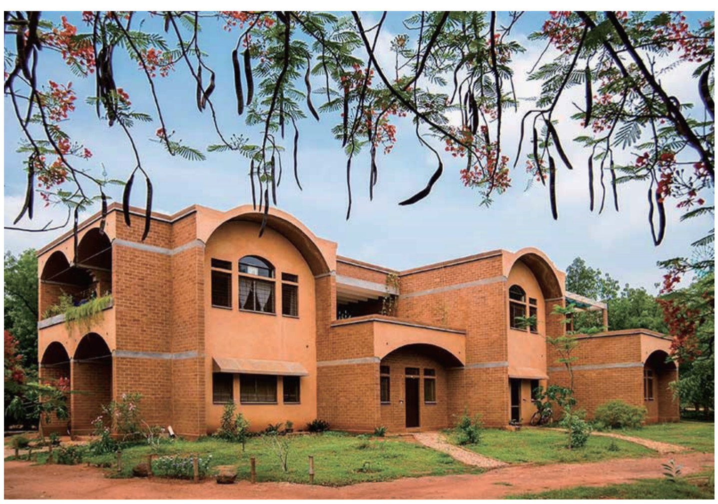

Figure 10. Compressed stabilized earth blocks in the Realisation Housing at Auroville, India

12. Conclusions

The engineering viability and characteristics of compressed earth blocks are covered in this paper. Compressed earth blocks have been discovered to provide indigenous populations with an inventive, sustainable, economical, and structurally sound building technique. No dangerous fumes are produced during manufacture. It is a cost-effective and environmentally responsible alternative to common building materials like brick and cement blocks. Earth construction is a cost-effective and resource-efficient method of building low-rise dwellings in underdeveloped nations. Bricks have become increasingly popular as a building infill material as a result of increased urbanization. Low-rise structures made of CEBs "are more durable and require less upkeep than the majority of residences" and "are generally more energy-efficient to manufacture than cement-based concrete materials." Even though compressed earth bricks may not be a viable option for every homeowner, they do provide a low-cost, more environmentally friendly alternative for those wishing to lessen the embodied footprint of their new house development (Roberts, 2019).

References

[1] Adlakha P. K., (2019). New Building Materials, and Technologies, Vol. IV, Indian Building Congress, New Delhi, India.

[2] Graham C.W. & Burt R. (2001), Soil Block Home Construction, BTEC Sustainable Buildings III Conference, Santa Fe, New Mexico.

[3] Powell D. (2021). Benefits of compressed earth blocks [Online], Available from https://greenbuildingcanada.ca/2012/benefits-compressed-earth-blocks-dan-powell-earthtek/

[4] Prasad T. (2020). Compressed Earth Block Engineering Aspects, [Online] Available from https://www.structuralguide.com/compressed-earth-block/

[5] Roberts, T. (2019). Compressed earth blocks for residential walls, [Online] Available from https://www.buildwithrise.com/stories/compressed-earth-blocks-for-residential-walls

[6] Kamal Arif M. & Husain A. (2015). Energy Efficient Sustainable Building Materials: An Overview', Sustainable Building Materials and Materials for Energy Efficiency, Key Engineering Materials, Vol. 650, pp. 38-50, Trans Tech Publication, Switzerland.

[7] Kamal, Arif M. (2016). Material Characteristics and Building Physics for Energy Efficiency, Materials and Construction Technologies for Sustainable Development, Key Engineering Materials, Vol. 666, pp. 77-88, Trans Tech Publication, Switzerland.

[8] Kamal, Arif M. (2011). The Study of Thermal Mass as a Passive Design Technique for Building Comfort and Energy Efficiency, Journal of Civil Engineering & Architecture, Vol. issue 1, pp. 84-88.

[9] Minke, G. (2000). Earth Construction Handbook, Southampton, U.K.: WIT Press.

[10] Schroeder W.L. & Dickinson S.E. (1996). Soils in Construction, Prentice Hall, Inc., fourth edition.